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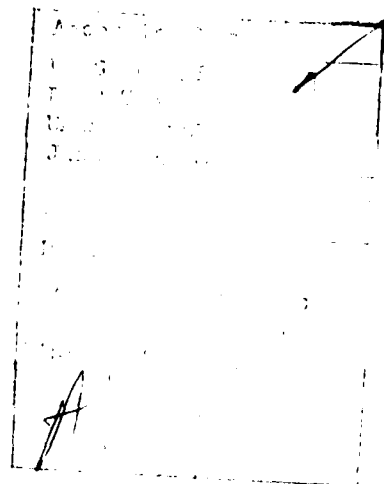
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The Salinity Effects of Deepening
the Dredged Channels in the
Chesapeake Bay

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ABSTRACT

Recent tests on the Chesapeake Bay Model, the world's largest estuarine model, were used to assess the effects of increasing the approach channels to Baltimore from 13 meters to 15 meters. There are four sections of dredged channels comprising 55 kilometers of the 277 kilometer distance from the bay mouth to Baltimore. The increased depth of channel would extend the length of dredged channels to 79 kilometers.

First, base tests using the existing 13-meter channels were conducted to determine the synoptic velocity, salinity, and tidal conditions at a number of locations throughout the bay but primarily in the dredged channels. To give meaningful results, a 2-1/2 year hydrographic period was simulated in the model to enhance the evaluation by adding the variable discharge as a parameter. Furthermore, a 12 constituent harmonic tide was used giving a 28-lunar-day tidal sequence which simulating a lunar month was repeated throughout the test. The entire test was repeated but with the 15-meter channel installed.

The primary result from the test is the comparison by location of the changes from base to plan of the salinity time histories which vividly show the effects of geometry, tidal and discharge changes.



INTRODUCTION

Chesapeake Bay, the largest estuary in the United States, is located on the East Coast and lies entirely within the Atlantic Coastal Plain. The Bay and its tributaries form a large estuarine system having a surface area of about 11,400 square kilometers and a shoreline of approximately 11,700 kilometers. The bay proper has a maximum depth of nearly 53 meters (off of Kent Island) and a mean depth of less than 8.5 meters. It is about 320 kilometers in length and varies in width from 6 kilometers near Annapolis to about 50 kilometers near the mouth of the Potomac River.

Chesapeake Bay receives the freshwater runoff from a drainage basin of 166,000 square kilometers including over 50 different tributary rivers. The Susquehanna River drains 42 percent of the basin, providing approximately 50 percent of the total freshwater inflow into the system. The Potomac River drains 22 percent of the basin, while the Rappahannock-York-James System drains about 24 percent. Two tides are introduced into the bay; one through the mouth and the other through the Chesapeake and Delaware Canal from the Delaware Bay. The mean tidal fluctuation in Chesapeake Bay proper is small, generally between 0.3 and 0.6 meters, while the ranges generally amplify progressively up the tributaries to their heads of tide. Average maximum tidal currents range from about one kilometer/hour to just over 3.5 kilometers/hour. Salinities range from less than 35 parts per thousand at the mouth of the bay to near zero at the heads of tide of both the bay proper and its tributary arms. Salinity variation (a function of the tidal and river inflow variations), both spatial and temporal, are the dominant factors causing the non-tidal, two-layered circulation pattern that provides a net seaward flow of freshwater in the upper layers of the bay, and the flow of salt water up the bottom of the bay.

CHESAPEAKE BAY MODEL

To address the many problems facing the bay the U.S. Army Corps of Engineers built a 3.2 hectare replica of the bay and its tributaries up to their heads of tide and housed it in a 5.7 hectare shelter. The model is a fixed bed distorted scale model constructed of hand-molded concrete, having a horizontal scale of 1 to 1,000 and a vertical of 1 to 100 - a scale distortion ratio of 10.

From the scale ratios, Froude law fixed the following relationship:

<u>Model</u>	<u>Factor</u>	<u>Prototype</u>
1 m	Depth	100 m
1 m	Length or width	1,000 m
10	Slope	1
1 cu m	Volume	100,000,000 cu m
1 cu m per sec	Discharge	1,000,000 cu m per sec
1 m per sec	Velocity	10 m per sec
1 day	Time	100 days
1	Salinity	1

MODEL APPURTENANCES

The model is equipped with the necessary appurtenances to reproduce and measure all relevant phenomena such as water-surface elevations, current velocities, freshwater inflows, and the salt content of the water. The appurtenances include Atlantic Ocean and Delaware Bay tide generation and salt water supply systems, inflow and outflow measuring devices, tide gages, current velocity meters, and conductivity meters.

The rise and fall of the tide in the model and the resulting flood and ebb tidal currents are reproduced by means of two automatic tide generators. The primary tide generator is located at the seaward end of the model and a secondary tide generator is at the eastern end of the Chesapeake and Delaware Canal. The primary tide generator maintains a differential between a gravity inflow of salt water from the ocean supply sump to the model and a gravity return flow from the model ocean to the return sump as required to reproduce all characteristics of the prototype astronomical tides in the ocean. The secondary tide generator, consisting primarily of an automated U-Notch weir is phased with the primary tide generator to reproduce the proper tidal conditions at the eastern end of the Chesapeake and Delaware Canal.

The model is equipped with 21 digital valves for precise metering of the freshwater inflow of all major tributaries. Each unit introduces the proper discharge for that particular stream, and incorporates discharges of all smaller streams between it and adjacent units. This permits reproduction of the freshwater inflows of the minor streams as well as the major rivers.

Freshwater inflows are achieved by passing water through a pressure regulated digital valve system. Each of the 21 valves had 8 solenoid operated orifices which allowed 255 different flow combinations.

Each orifice is half the area of the next larger orifice. The range and step size is a function of the set of eight orifices in the digital valve.

The primary controlled parameters are tides, freshwater inflow, and source salinity. The latter is handled manually. The inflows are set manually for steady state operations and by the computer for hydrograph simulation while the tides are controlled by an electromechanical cam system for repetitive tides and by the computer for variable tides.

The model computer control and data acquisition system includes a Texas Instruments 960-B mini-computer with a 40 K memory, a Sykes floppy disc unit and a Texas Instruments 733 ASR Electronic Data Terminal equipped with two cassette transports and a 30-character-per second printing rate. Control information including calibrations, input tide heights, and inflow valve discharges are entered on a floppy disc. This is used as input to the TI 960 to provide instructions for ocean and C & D tide generators and the 21 inflow valves. Feedback from the flowmeters and automated water surface detectors is received and recorded on the floppy discs, and upon command, printed by the terminal for real-time monitoring.

Data communications is achieved between the computer and the model electronics via SERDEX (serial data exchange) system. The Chesapeake Bay Model utilizes 10 multiplexer (MUX) units and 25 transmit/receiver (Tx/Rx) units to (a) send instructions from the computer to the inflow valves and tide generators, and (b) send information from the transducers to the computer in digital ASCII code by a fully duplexed 2-wire transmission line.

The SERDEX Tx/Rx units are capable of converting analog signals to binary coded decimal signals which are compatible with the SERDEX Tx inputs. The SERDEX Tx converts this information to serial ASCII code which is then transmitted to the computer on command. The SERDEX Rx converts serial ASCII from the computer into parallel digital information which is fed to digital-to-analog converters or to a digital input device such as the digital valve.

MODEL OPERATION

Much previous estuarine physical model work involved using repetitive tides and constant inflow discharges. Repeating a test with three tidal conditions--neap, mean, and spring--an envelope of data would be produced to give predictive information. The Chesapeake Bay System is too large to use such an approach. The need for producing variable tides over a period corresponding to a lunar month and repeating this sequence while varying the inflows temporally as would occur in nature necessitated computer control. This has allowed the reproduction of variable tides and inflows easily enabling accurate reproduction of events occurring throughout any given or projected water year or years.

Testing on the Chesapeake Bay Model has shown vertical salinity structural response not just due to river flows but to the sequencing of tides during a lunar month. This has further been supported by prototype data. If the salinity responds to the change in tide as it

cycles from neap to spring, then it is reasonable to assume that the vertical distribution of other water quality parameters also mirror the tidal as well as inflow conditions.

To properly account for tidal variation in the prototype, a model source tide was programmed based upon 12 harmonic constituents. This allowed for the reproduction of astronomical tides and tidal variance from cycle to cycle with closure after 56 tidal cycles of 28 lunar days. This 28-lunar-day tide is employed in any study where water quality parameters are important (usually salinity and dye dispersion).

BALTIMORE HARBOR CHANNELS STUDY

The first major study involving the Chesapeake Bay Model was to assess the impact of increasing the depth of the channels leading from the mouth of the bay to Baltimore from 13 meters to 15 meters. The channels leading to Baltimore are in four reaches (See Figure 1). Starting at the bay entrance is the Cape Henry Channel, followed by the York Spit Channel, the Rappahannock Shoal Channel, and finally that series of continuous channels initiating just outside the entrance to the Patapsco River and terminating at Baltimore. These channels constitute 55 of the 277 kilometers from the ocean to Baltimore. Construction of the 15-meter channels would require the dredging of 54 million cubic meters of material and result in a 24-kilometer increase in total length of dredged channels.

The study was divided into two main portions - the steady state tests and the "hydrograph" tests. The former consisted of four tests with the following distinctive boundary conditions:

<u>Bay Discharge, cms</u>	<u>Type Tide</u>
3,400	spring
3,400	neap
850	neap
850	spring

The hydrograph tests employed a 28-lunar-day repetitive tide and a weekly stepped, 2-1/2-year-long hydrograph covering April 1964 to October 1965 plus an average or modal year.

Both the steady state and the hydrograph tests consisted of a base, using the present dredged channel dimensions, and a plan, using the authorized channel dimensions. In all cases, the desired source salinity in the ocean was 32.5 ppt and was allowed to vary between 2-5 ppt at the Delaware Bay end of the C & D Canal. The target net C & D flow for all tests was 0 cfs. The purpose of the study was to assess:

- a. Velocity characteristics at 13 stations in the model during steady state operations and the effect the deepened channels would have upon velocities.
- b. Salinity and tidal characteristics at 68 and 10

locations, respectively, during an historic period (April 1964 - October 1965) and an average or modal period.

- c. Changes that the deepened channels would make on salinity and tidal measurements by comparing to b. above.
- d. The effect discharge would have on velocity and salinity.
- e. The effect tide range would have on velocity and salinity.

CONCLUSIONS FROM STEADY STATE PORTION

Velocities in Chesapeake Bay are relatively low. During the test, maximum velocity exceeded 1 mps only at one station and that was in the York Spit Channel.

The tide is far more significant than discharge in affecting the velocities for the stations observed. But even the tide (spring vs. neap) seldom caused a difference between maximum measured velocities to exceed 0.2 mps. Those few changes of that magnitude were located in the Virginia portion of the bay where velocities and tidal ranges are the greatest (See Figure 2). The apparent reason for the small change in velocities comparing those measured during spring tides against those during neap tides is that despite the source tide, the middle portion of the bay has a relatively fixed and low tide range.

Only two velocity stations were located inside the Patapsco River. Under no test conditions did the maximum velocities at these stations exceed 0.2 mps. No shift in flow predominance was identified between base and plan which could clearly be used for conclusions about the effects of depth change upon sediment transport.

Salinities did respond to the variations of tide range and discharge. The test data show that:

- a. The discharge exerted greater influence than tide in limiting salinity intrusion.
- b. Spring tides provide better mixing.
- c. Stratification increased with discharge.
- d. Maximum mixing occurred with the spring tide and 850 cms discharge.
- e. The deepened channels generally did not raise salinities more than 2 ppt at the locations monitored which were positioned outside of the dredged channels.

CONCLUSIONS FROM THE HYDROGRAPH PORTION

Salinity data do show a definite response to geometry changes. Generalizing:

- a. The model appears to be more saline during the plan

test than the base test.

- b. Salinity differences between base and plan are more pronounced in the Patapsco and surrounding bay area and are most evident in the dredged channels within that area.
- c. Salinities are markedly greater at bottom depths in the dredged channels for the area specified in b. above during the plan and exhibit a fresher surface yielding a much greater vertical salinity difference.
- d. The deepened plan depths appear to induce higher salinities in the Patapsco and surrounding bay area. Salinity differences, base to plan, in this area attenuate with distance from the deepened channels.

An interesting comparison can be made between the Patapsco and Magothy estuaries. In the dredged channels in the Patapsco the salinities were generally well mixed during the base but became partially mixed after the channels were deepened (See Figure 3). The middepth and bottom salinities increased while several of the surface salinities decreased. Just south of the Patapsco is the Magothy and here the salinities were well mixed during both base and plan but, curiously, during the peak discharges during both water year 1965 and the modal year, the plan salinities were about 1-5 ppt less at surface and bottom than during the base (See Figure 4). Because the two Magothy sampling depths (1.2 and 5.4 meters) were in relatively shallow water, this observation may be reflective of stratification tendencies during high discharge being aggravated during the plan test, with higher bottom salinities in the deeper natural and/or artificial channels resulting in decreased surface and near surface salinities directly in the channel and laterally away from it.

At many stations, the 28-lunar-day tide had a visible effect on salinities in the form of a response to mixing as a result of the spring/neap relationship. The occurrence of this effect appears to be a function of discharge (more obvious during higher discharge, Figure 5), geometry (where only seen in plan at dredged channels in the Patapsco, Figure 3), and tide range (more pronounced at locations with higher ranges, Figure 5). There are exceptions to each of these parameters which makes generalization difficult and application to other locations unwise.

At shallower locations and with increased distance from the ocean, the salinities were more responsive or reflective of discharge. Bottom salinities become less responsive first as the ocean is approached. Better mixing is achieved during the lower discharge portions of the hydrograph.

During the last half of the modal year, the model operated with a cam-driven repetitive tide with a mean range. The resultant salinity characteristics at most locations (the mouth of the Potomac was a notable exception) reflected the changed source tide in that salinity values had less variability (or were smoother) with respect to time, they were better mixed, and the differences between base and plan seemed slightly less (See Figure 6).

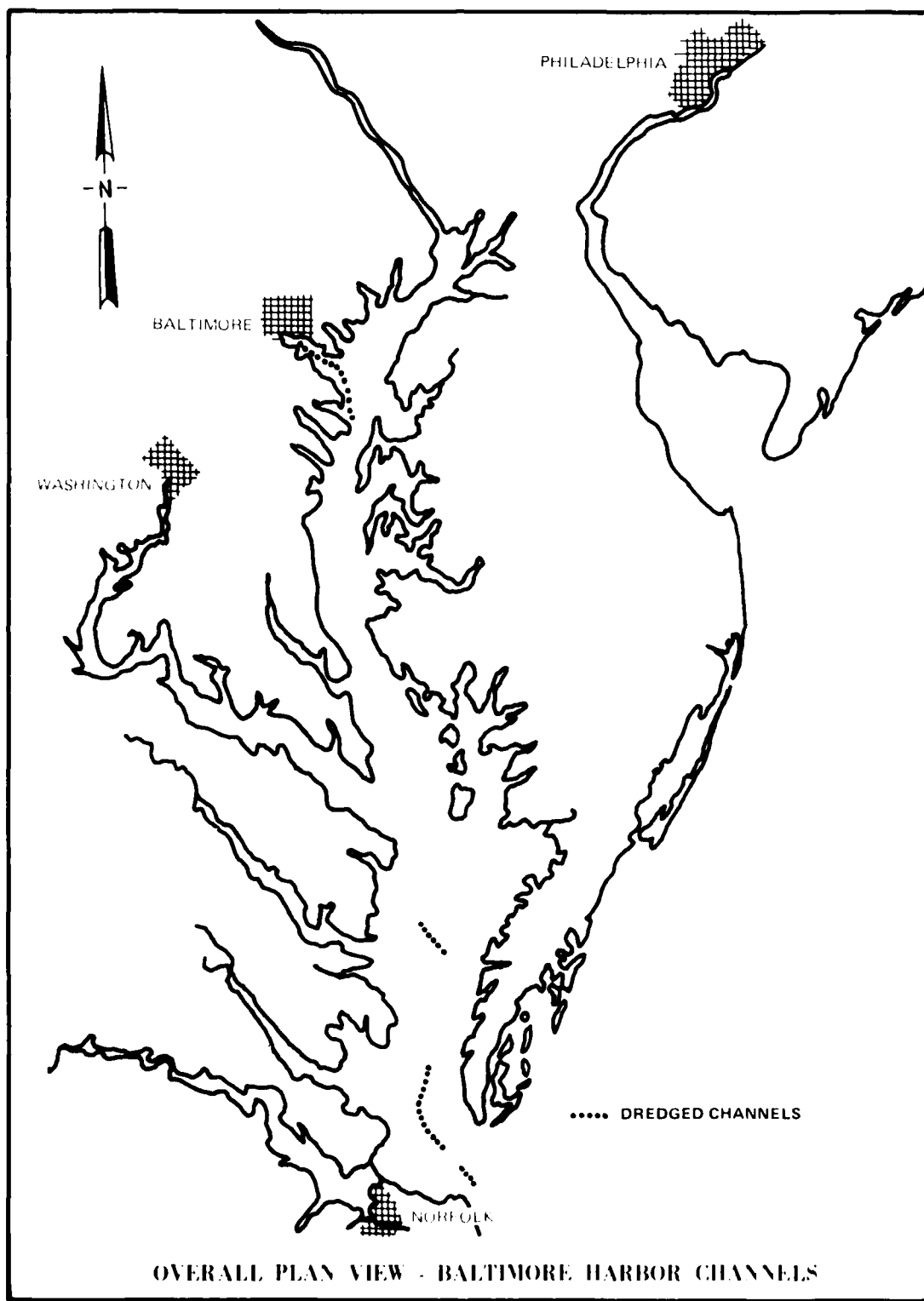


Figure 1

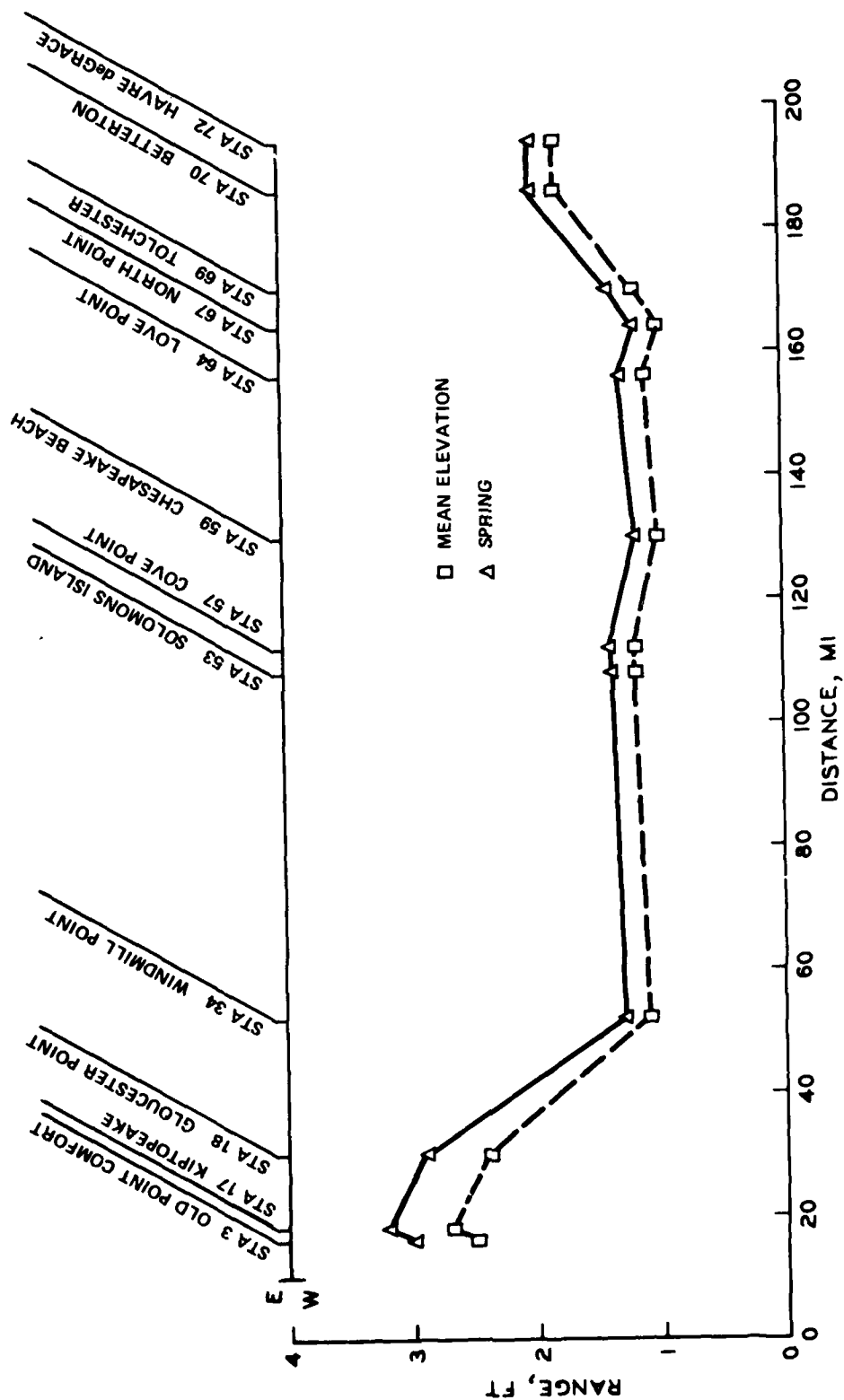


Figure 2 Chesapeake Bay tide ranges versus distance from the mouth of the bay.

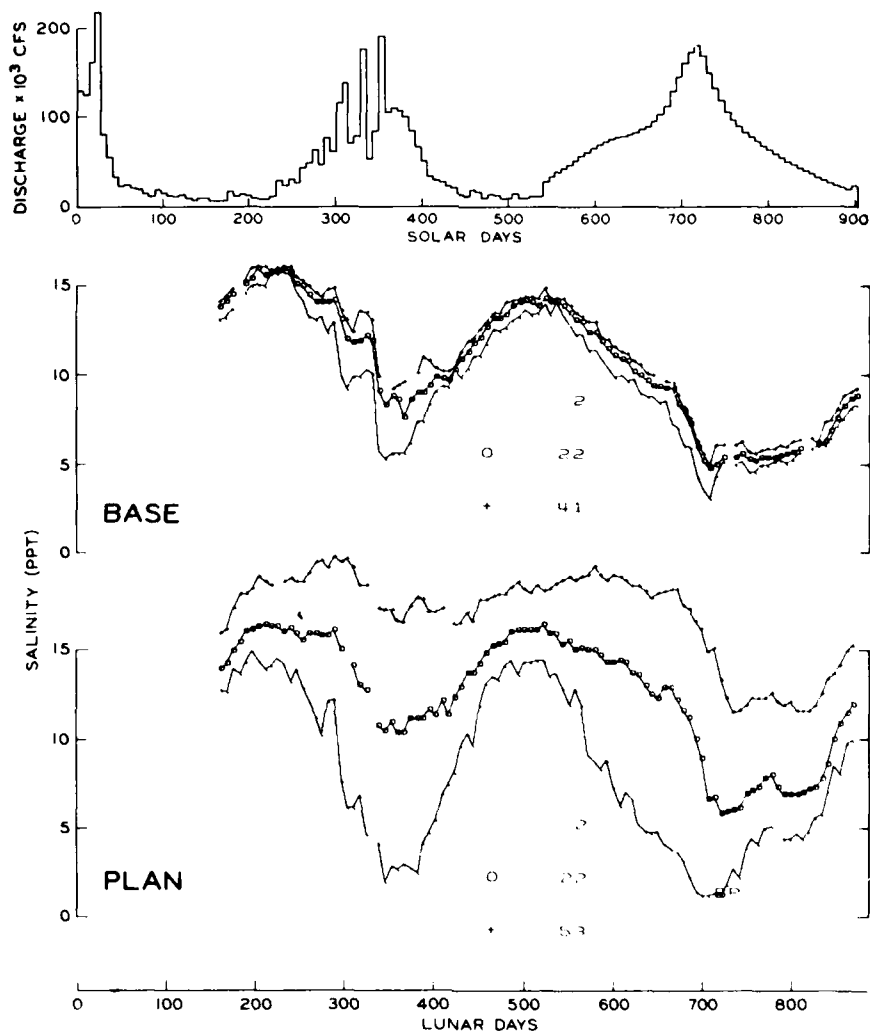


Figure 3 Salinity time histories for 3 depths (ft) in the dredged channels near the mouth of the Patapsco River versus total bay freshwater discharge.

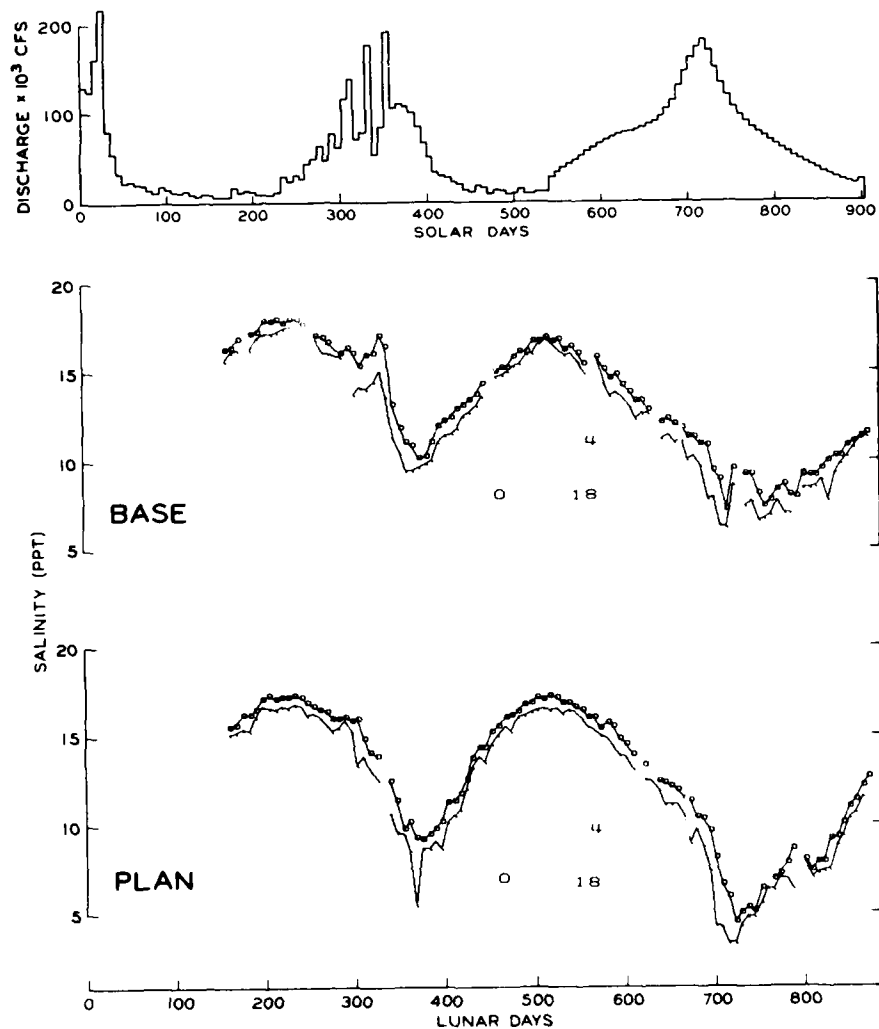


Figure 4 Salinity time histories for 2 depths (ft) at the mouth of the Magothy River versus total bay freshwater discharge.

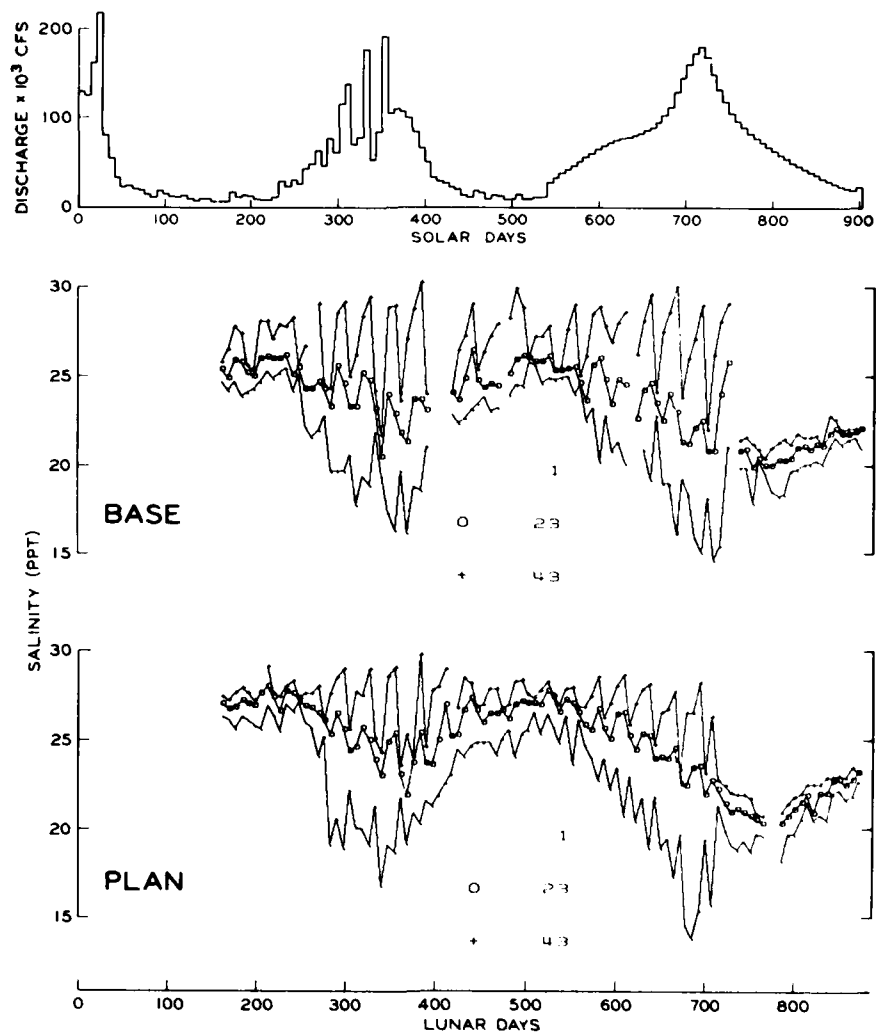


Figure 5 Salinity time histories for 3 depths (ft) at the mouth of the James River versus total bay freshwater discharge.

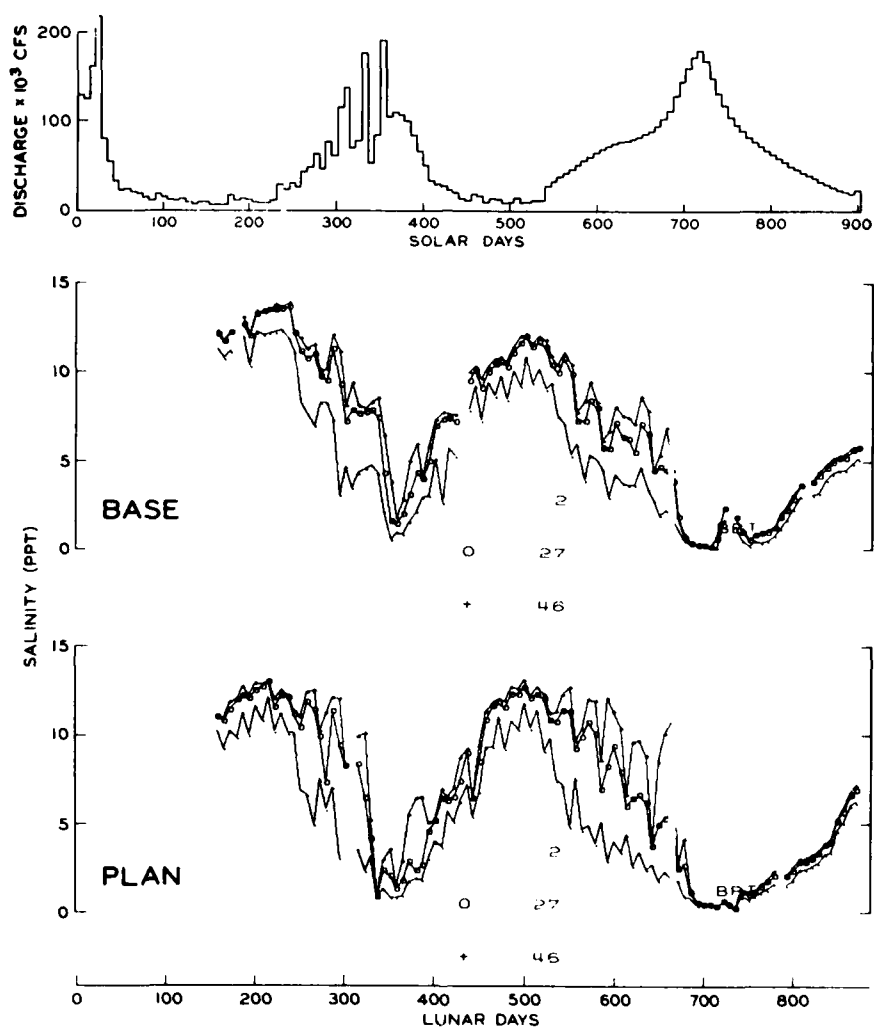


Figure 6 Salinity time histories for 3 depths (ft) in the Chesapeake Bay above Baltimore versus total bay freshwater discharge.

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